# Biochar characterization and impacts on agricultural soils of the temperate region

## Effects on soil fertility, crop yield and trace element behavior

Universität für Bodenkultur Wien
Department für Wald- und Boden-
wissenschaften

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***"BURNING ISSUES IN SOIL SCIENCE"***
***ANNUAL CONFERENCE OF AUSTRIAN SOIL SCIENCE SOCIETY***

22. September 2014

# Outline

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Introduction

- What is biochar?
- Biochar properties
- The Austrian BIOCHAR project
- Objectives

Results

- Characterization of slow pyrolysis biochars
- Impacts of biochar on soil fertility and plant growth
- Trace element behavior in biochar-amended soils

Conclusions

# Introduction

***What is biochar?***

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**Pyrolysis** Thermal decomposition of biomass under low-oxic conditions and relatively low temperatures (< 700°C)

↓

**Biochar** Carbon-enriched, aromatic solid product resulting from pyrolysis of biomass

→ **Soil amendment, C sequestration**

Role model: **Amazonian Terra Preta soils**

Anthrosols: Pottery, animal and human waste, **charred organic material**
→ higher pH, increase in Soil organic matter, higher cation exchange capacity

Radiocarbon dating: charcoal up to 7000 years old

Terra Preta | Ferralsol

www.Ithaka-journal.net

# Introduction

*Biochar properties*

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**FEEDSTOCK**
(wood, nutshells, straw, poultry litter)

**PYROLYSIS CONDITIONS**
(temperature, residence time, heating rate,…)

volatilization, loss of C, N, H, decarboxylation, decarbonylation, dehydration, depolymerization

PYROLYSIS

## Biochar properties

**Changes in elemental ratios**

decrease of O/C, H/C ratios→ stability, aromaticity

Stable C pool

increase of C/N , enrichment in C

**Increase in specific surface area, porosity**

→ cation exchange capacity, habitat for microorganisms

**Increase in pH and ash content**

due to enrichment of alkaline, inorganic compounds

**Enrichment of nutrients (but: potentially toxic compounds)**

**C sequestration potential**

**Increased water and nutrient holding capacity, soil remediation potential**

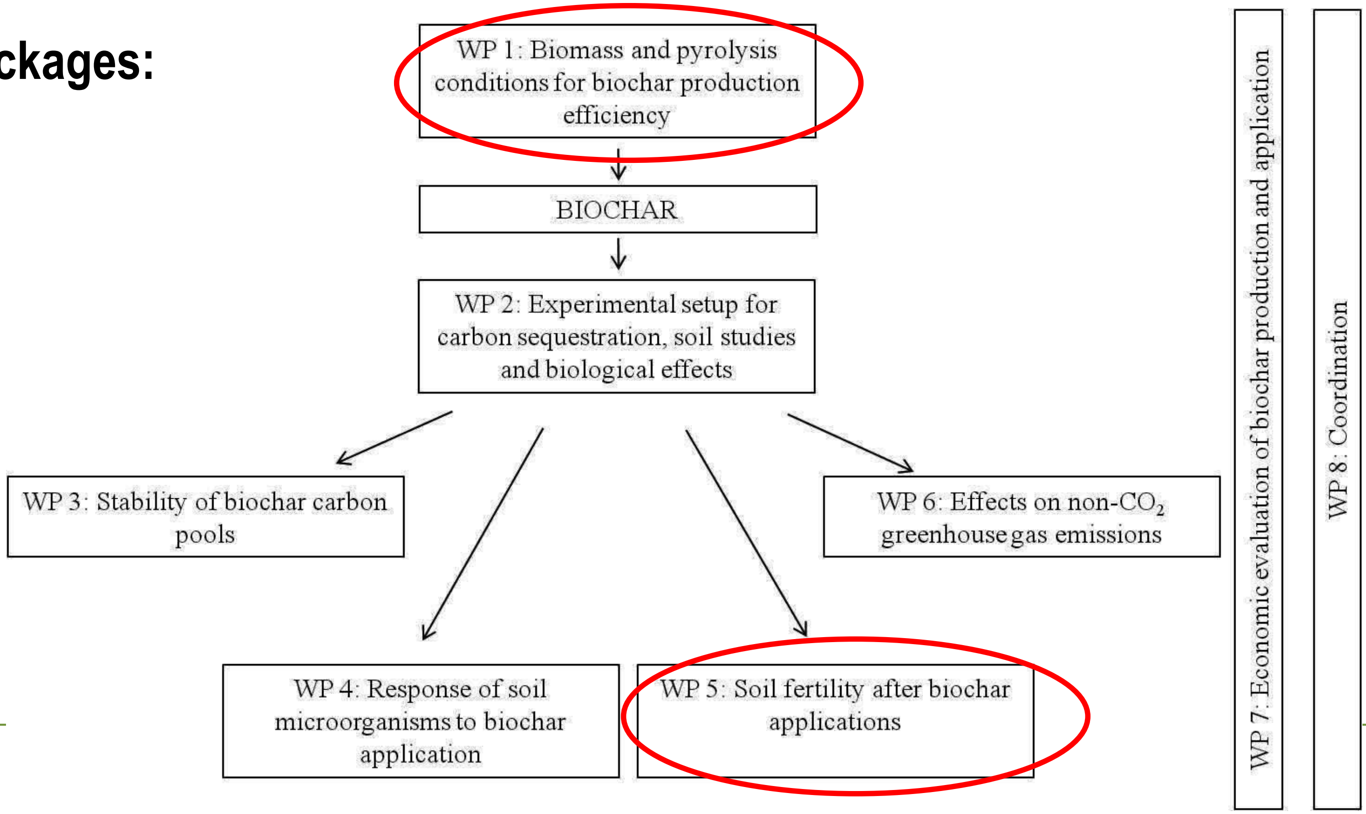
# Introduction

***The Austrian BIOCHAR project***

*“Biochar for Carbon Sequestration in Soils: Analysis of production, biological effects in the soil and economics”*

Project period: April 2010- June 2013

**8 work packages:**



# Introduction

***Objectives***

**Characterization of different biochars**

Influence of **feedstock and pyrolysis temperature**

Formation/ accumulation of **potentially toxic compounds**

Kloss et al. (2012), *Journal of Environmental Quality* 41, 990-1000; cited 46 times

glasshouse pot experiment

## Soil fertility/ crop growth and composition

- **Varying biochar application rates on different soils** (Planosol, Cambisol, Chernozem)
- **Different biochar types on one soil** (Planosol)
- Different N fertilization rates with/ without biochar

Kloss et al. (2014), *Journal of Plant Nutrition and Soil Science* 177, 3-15

## Trace element behavior in soil-water-plant system

- **Varying biochar application rates on different soils** (Planosol, Cambisol, Chernozem)
- Different biochar types on one soil (Planosol)

Kloss et al. (2014), *Science of the Total Environment* 481, 498-508

Kloss et al. (2014), *Environmental Science and Pollution Research*, under revision.

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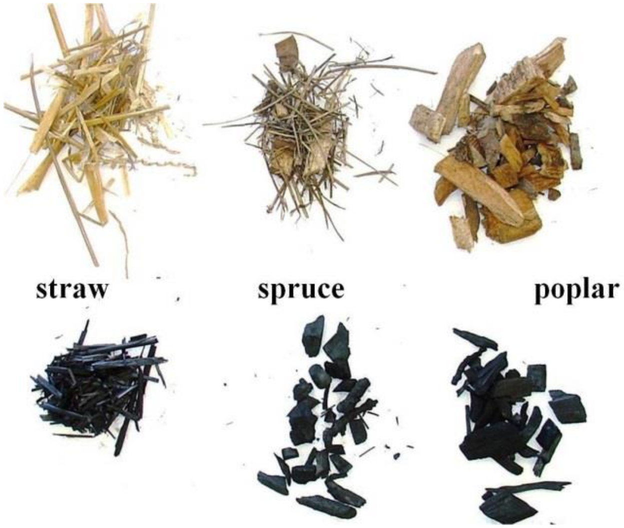
# Results

***Biochar characterization***

- **Three feedstocks** slowly pyrolyzed
  (*Triticum aestivum, populus tremula, picea abies*)

- **Three pyrolysis temperatures**:
  400°C, 460°C, 525°C

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**<u>Basic characterization</u>**

- **pH**
- **Electrical conductivity (EC)**
- **Ash content**
- **Cation exchange capacity (CEC)**
- **Specific surface area (BET-$N_2$)**
- **Total C, N and H**
- **Water-extractable major elements**
- **Ash composition (XRF)**

**<u>Molecular/ mineralogical characterization</u>**

- **Differential Scanning Calorimetry (DSC)**
- **Fourier-Transform Infrared Spectroscopy (FTIR)**
- **X-ray diffraction (XRD)**

**<u>Ecotoxicologically relevant parameters</u>**

- **Water extractable trace elements**
- **Polycyclic aromatic hydrocarbon (PAH) content and composition (EPA 16)**

# Results

## *Biochar characterization*

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## Basic characterization

| | pyrolysis temperature | pH $(CaCl_2)^{\dagger}$ | EC $(mS\ cm^{-1})^{\dagger}$ | ash $(wt.\%)^{\dagger}$ | C $(wt.\%)^{\ddagger}$ | SSA $(m^2 g^{-1})^{\ddagger}$ | CEC $(mmol_c kg^{-1})^{\ddagger}$ | PAHs $(mg\ kg^{-1})^{\ddagger}$ |
|---|---|---|---|---|---|---|---|---|
| straw | feedstock | | | 3.6 | 44.2 ± 0.4 a | | | |
| | 400°C | 9.1 | 1.08 | 9.7 | 65.7 ± 1.9 b | 4.8 ± 0.5 a | 161.6 ± 15.6 e | 5.2 ± 2.9 a |
| | 460°C | 8.7 | 4.92 | 12.0 | 72.4 ± 4.9 bcde | 2.8 ± 1.8 a | 117.0 ± 21.2 cd | 10.7 ± 5.6 ab |
| | 525°C | 9.2 | 4.43 | 12.7 | 74.4 ± 4.9 cde | 14.2 ± 4.0 a | 97.7 ± 19.4 bc | 33.7 ± 22.1 b |
| poplar | feedstock | | | 1.1 | 46.1 ± 0.8 a | | | |
| | 400°C | 9 | 1.04 | 3.5 | 67.3 ± 0.8 bc | 3.0 ± 0.6 a | 144.0 ± 5.6 de | 4.3 ± 1.8 a |
| | 460°C | 9.2 | 0.70 | 5.7 | 70.0 ± 0.0 bcd | 8.2 ± 0.1 a | 128.3 ± 17.7 cde | 17.9 ± 3.6 ab |
| | 525°C | 8.7 | 0.86 | 6.8 | 77.9 ± 1.0 de | 55.7 ± 19.5 b | 107.6 ± 7.6 bcd | 2.0 ± 0.8 a |

† single determination
‡ determined in triplicate (means ± standard deviation)

**Pyrolysis temperature has important influence on most properties**

**Accumulation of ash, carbon**

**Increase of specific surface area, but decrease of CEC**

Kloss et al. (2012), *Journal of Environmental Quality* 41, 990-1000

# Results

## *Biochar characterization*

### Molecular characteristics of poplar feedstock and biochars

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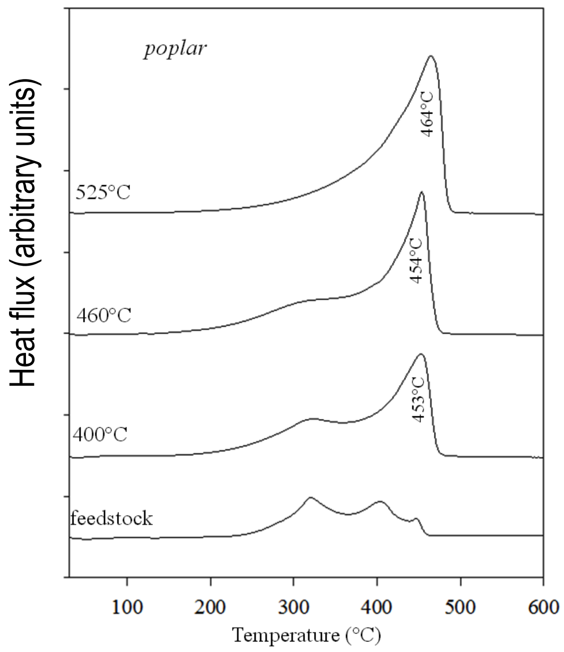
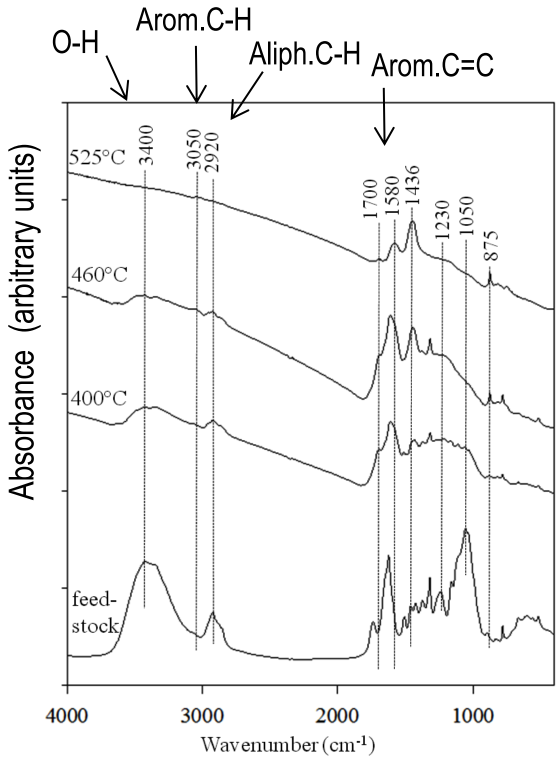
**Differential scanning calorimetry (DSC)**




→ Increase in aromaticity/(thermal) stability with increasing pyrolysis temperature

**Fourier-Transform Infrared Spectroscopy (FTIR)**




→Net decrease of functional groups with increasing pyrolysis temperature

Kloss et al. (2012), *Journal of Environmental Quality* 41, 990-1000

# Results
***Biochar characterization***

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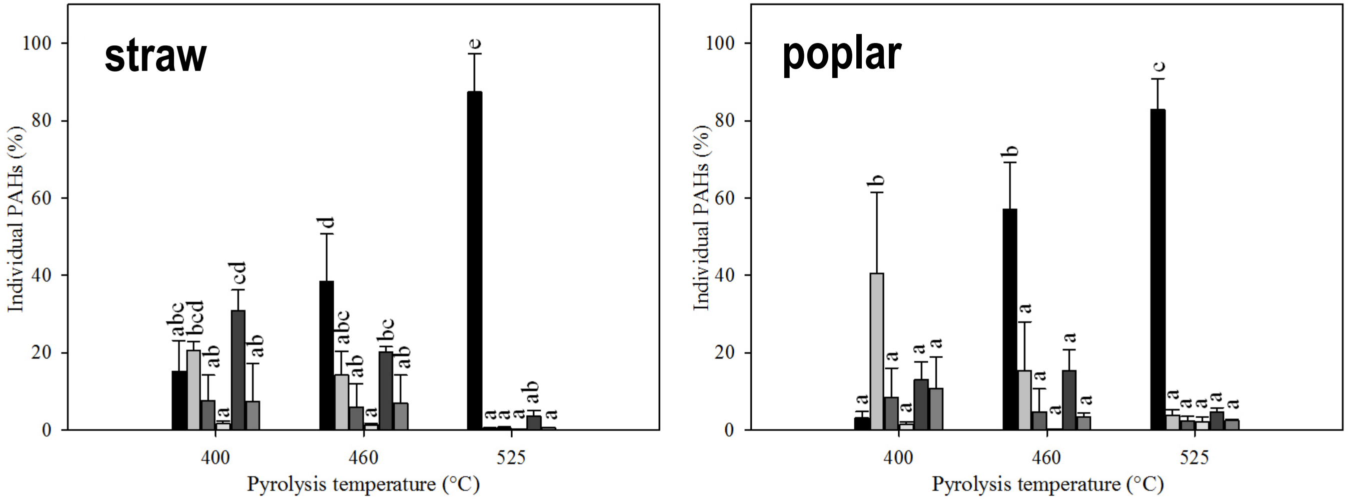
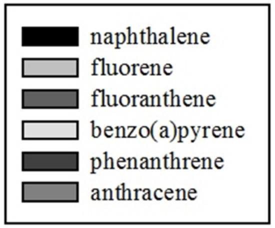
## Individual PAHs in % of total PAH composition (based on US EPA 16)




→ Increasing dominance of naphthalene with increasing pyrolysis temperature

Kloss et al. (2012), *Journal of Environmental Quality* 41, 990-1000

# Pot experiment: Design

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**Four different biochars:**

Wheat straw [525°C]
Mixed woodchips [525°C]
Vineyard pruning [525°C]
Vineyard pruning [400°C]

**Two application rates:**

1 and 3 w.-%
(equals 30 and 90 t $ha^{-1}$)

**Start in Nov. 2010**

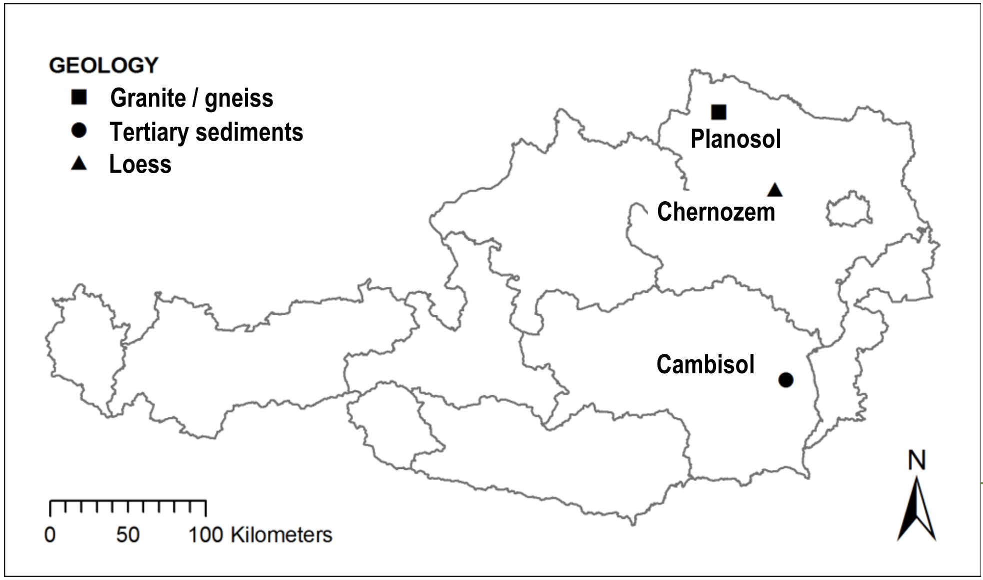
**Three soils:**

Planosol (sandy loam, pH 5.4)
Cambisol (clay loam, pH 6.6)
Chernozem (silt loam, pH 7.4)

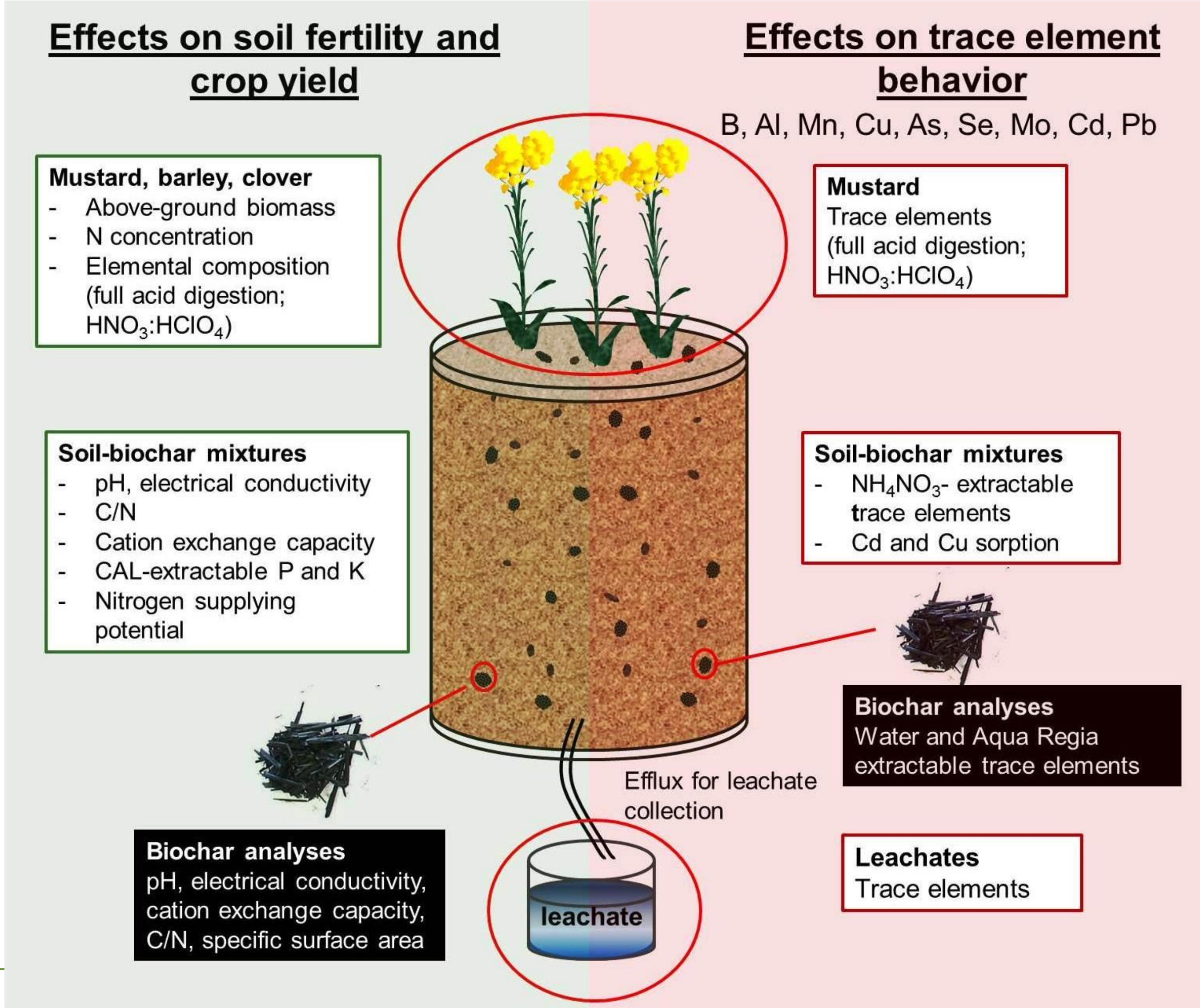
**Three successive crops:**

Mustard (*Sinapis alba* L.)
Barley (*Hordeum vulgare* L.)
red clover (*Trifolium pratense* L.)

fertilization:
Mustard: 40 kg N $ha^{-1}$
barley: 100 kg N $ha^{-1}$




# Pot experiment: Analyses



# Results

## *Soil fertility and crop growth*

***Effects of different biochars on Planosol***

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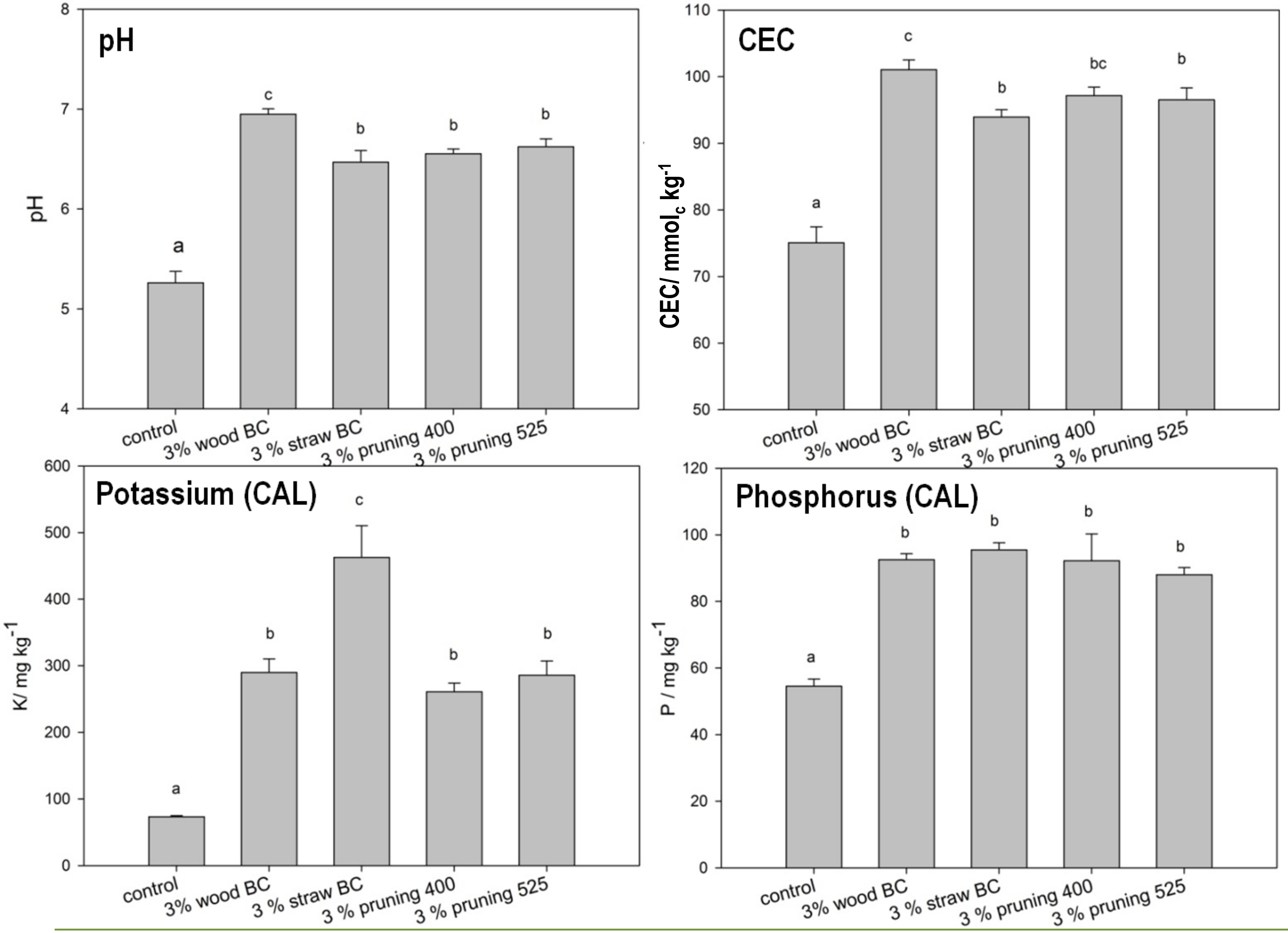


→ Significant increase of pH and CEC for all BC types on the **acidic sandy Planosol**

→Increase in P and K extractability (CAL) (esp. straw)

**No influence of pyrolysis temperature!**

**(after 7 months)**

**Kloss et al. (2014), *Journal of Plant Nutrition and Soil Science* 177, 3-15**

# Results

## *Soil fertility and crop growth*

***Effects of different biochar types on crop yield (Planosol)***

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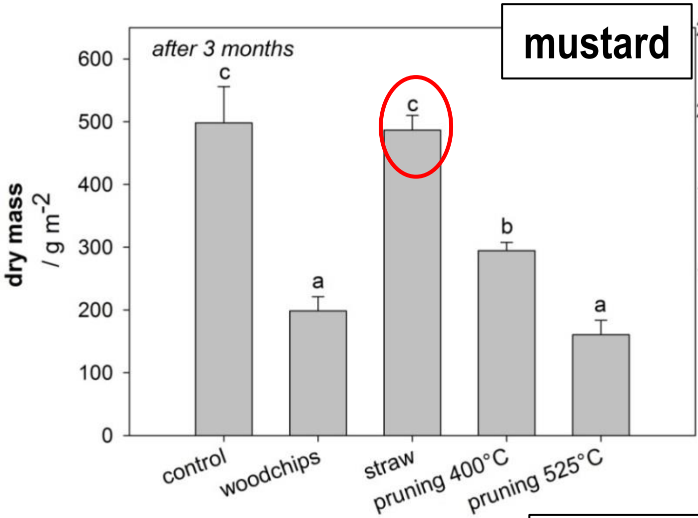
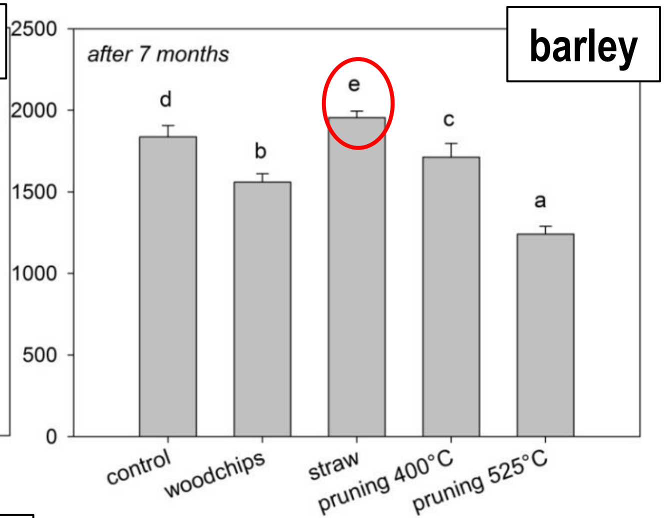
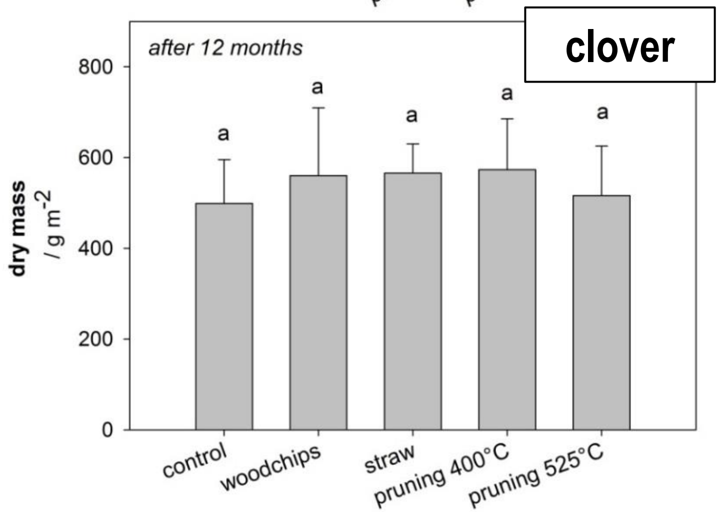



- **Initially detrimental effects** (except for straw biochar)
- **...se in above-**
  **biochar a...**
  crop
- **Influence of pyrolysis temperature**

**WHY SUCH CONSIDERABLE YIELD DECREASES?????**

Kloss et al. (2014), *Journal of Plant Nutrition and Soil Science* 177, 3-15

# Results

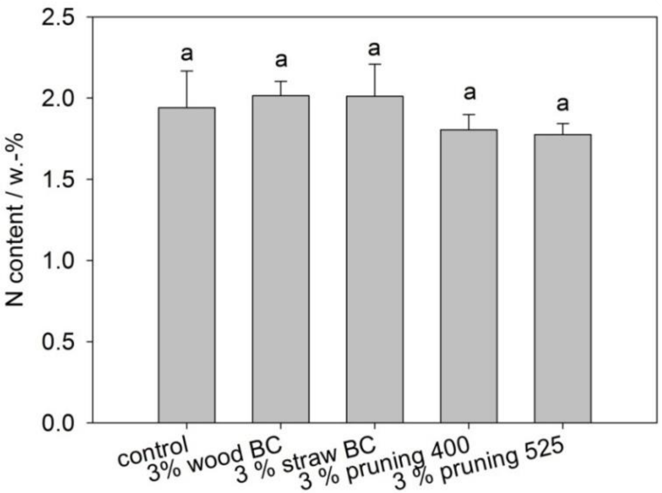
## *Soil fertility and crop growth*

***Potential causes for initial yield inhibitions***

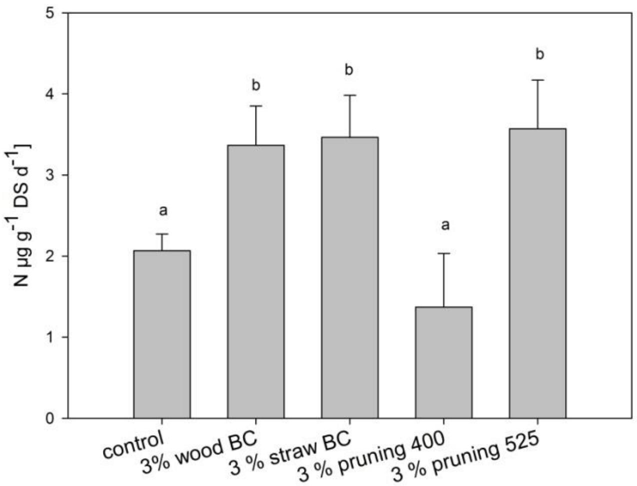
*"BC application to soil causes **N deficiency** in plants"* (Rondon et al., 2007; Collison et al., 2009,…)

*"pH increase may cause **micronutrient deficiencies**"* (Marschner and Rengel, 2012)

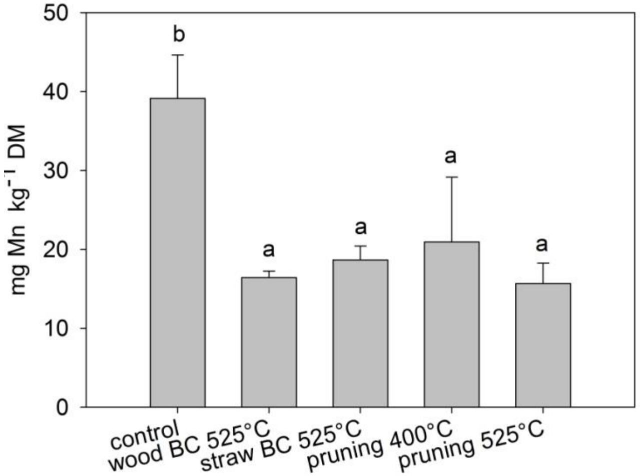
**N concentration in mustard**




**Soil nitrogen supplying potential**




**e.g. Manganese (mustard)**



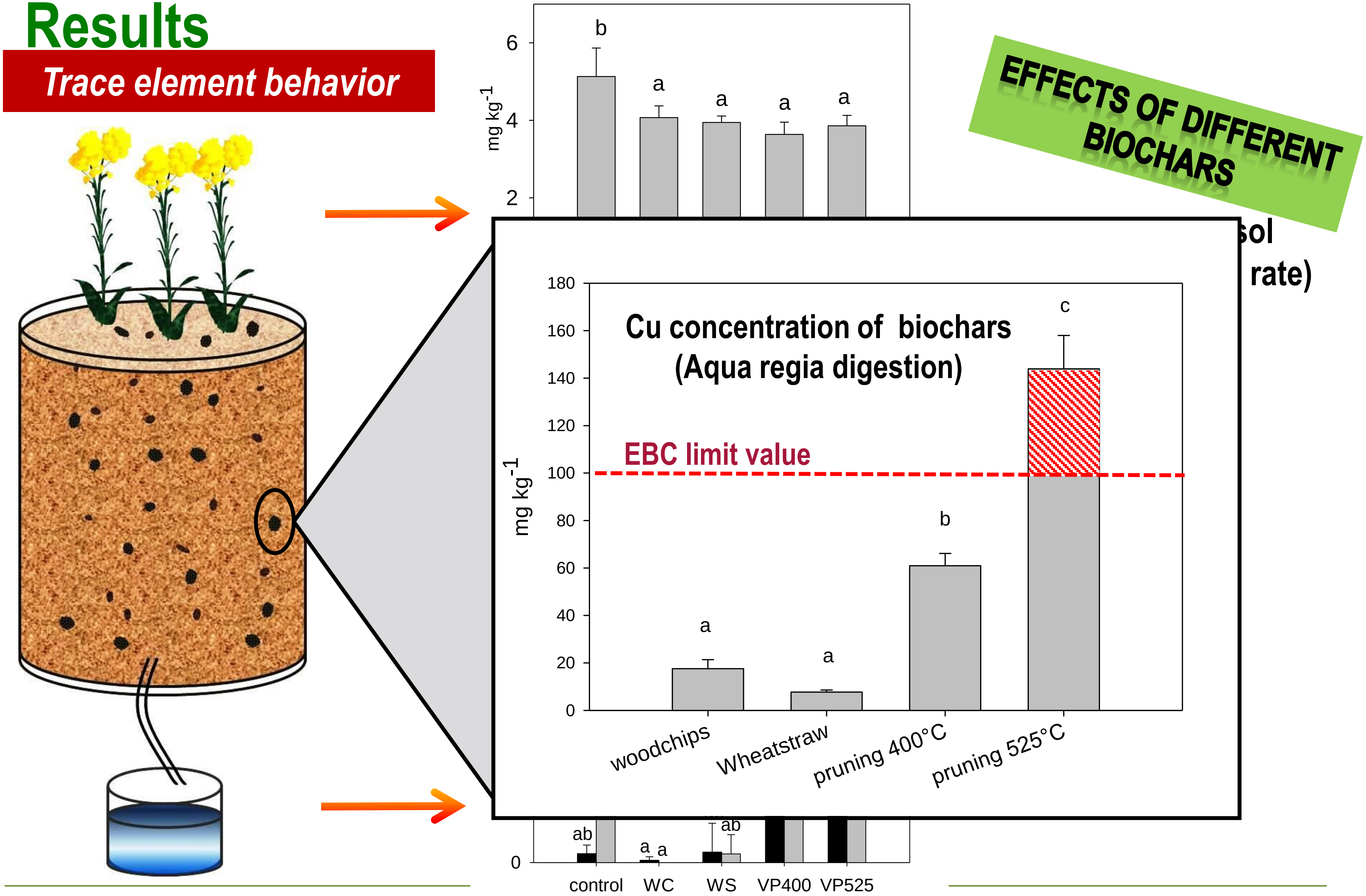

No or negligible N-immobilization ; increased nitrogen supplying potential (except for VP400)

Micronutrient deficiency?

Kloss et al. (2014), *Journal of Plant Nutrition and Soil Science* 177, 3-15

# Results

## *Trace element behavior*

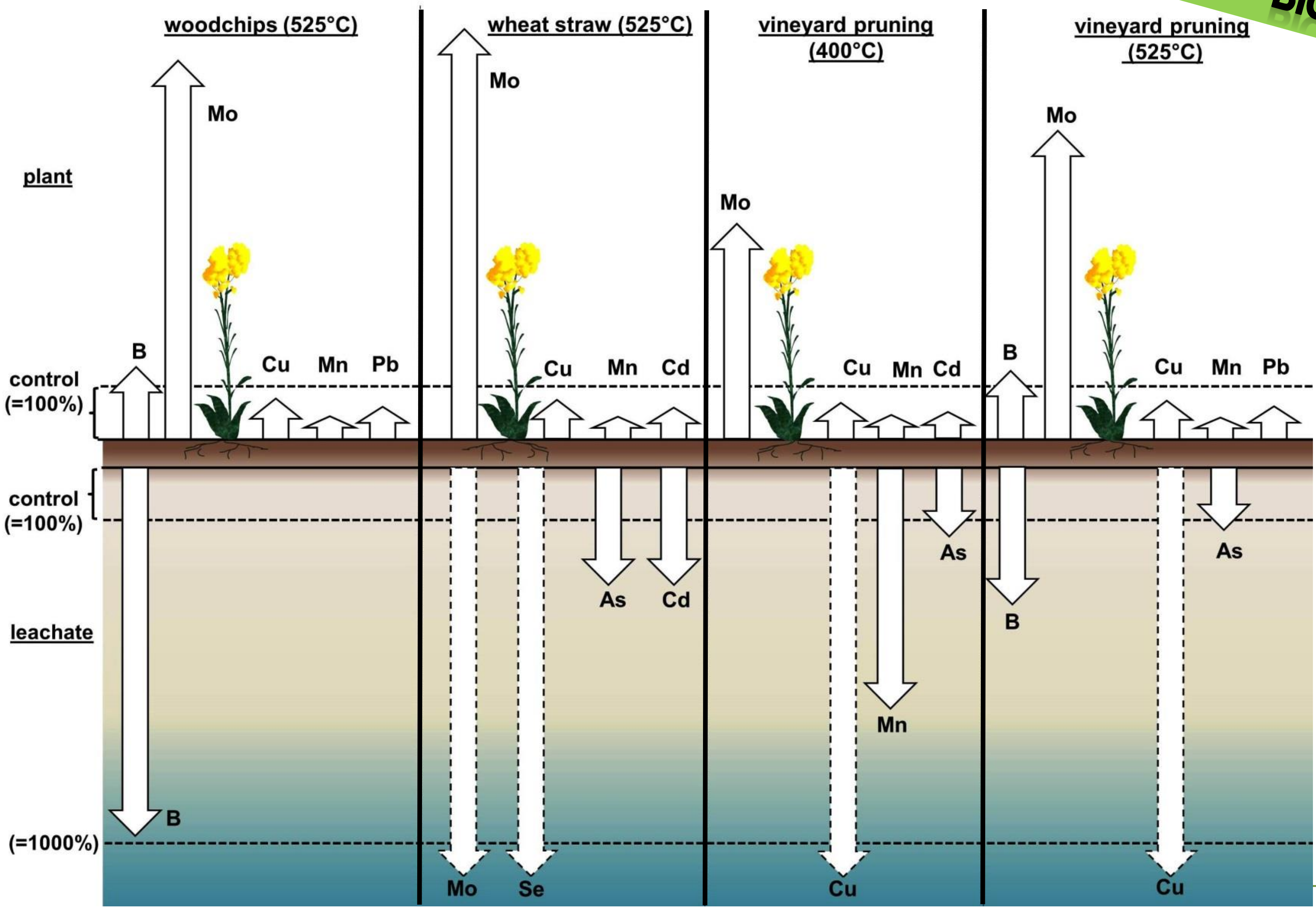



Kloss et al. (2014), *Environmental Science and Pollution Research* (in review)

# Results

## *Trace element behavior*

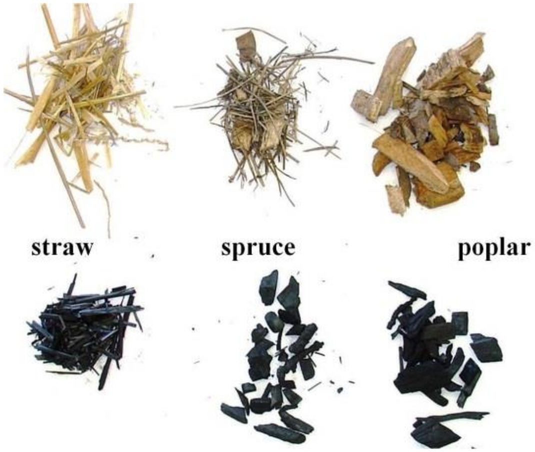
EFFECTS OF DIFFERENT BIOCHARS




Kloss et al. (2014), *Environmental Science and Pollution Research* (in review)

# SUMMARY

## Biochar characterization




Properties of biochar dependent on **feedstock and pyrolysis temperature** (CEC, SSA, ash content)

Increased C content and aromaticity

USEPA PAH limit in biosolids (6 mg $kg^{-1}$) clearly exceeded (up to 33.7 mg $kg^{-1}$ in straw biochar); change of PAH composition→ **ecotoxicologically relevant**

All biochar types positively affected soil pH, cation exchange capacity of an acidic Planosol

**Short-term detrimental effects** on crop yield upon biochar application (except wheat straw biochar)

Biochar application affected **trace element behavior,** partly due to a direct input of trace elements

# CONCLUSIONS

The application of biochar on temperate **as a soil amendment** may be overall **less favorable** than in tropical soils (role model Terra Preta), but strongly depends on biochar and soil type

In temperate regions, the **"amendment effect"** may be limited to degraded soils

**Potential soil-conditioning effect masked by (short-term) crop decreases**
→ Different pre- post treatments; feedstocks, pyrolysis conditions
→ Alternative application purpose

→ **Mitigation of climate change**
→ **Nitrogen use efficiency/ decreased nitrogen loss**
→ **Soil remediation potential** for cationic trace elements (Cd, Pb)
However: BC application may increase solubility of anionic trace elements **(deficiency vs. toxicity)**

**In view of ecotoxicological relevance:** biochar standardization/ quality control

long-term (field) experiments needed (other effects may become relevant→ increased water holding capacity)

# SPECIAL THANKS TO…

Assoc. Prof Dr. Franz Zehetner and PD Dr. Gerhard Soja for supervision and support as well as the whole biochar team

Prof. Gerzabek for his support

Astrid Hobel, Elisabeth Kopecky, Karin Hackl, Angelika Hromatka, Ewald Brauner, Axel Mentler for their lab support

FFG / New Energies 2020 project number: 825438

**Last but not least:**
**the Austrian Soil Science Society for the Kubiena Forschungspreis!**